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Evaluation of Composite Method Repair of a Cracked Plate

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Abstract: This work evaluates the performance of composite patch repairs for cracked aluminium plates by examining various parameters including patch shape, height, thickness, the influence of stress on the patch, and adhesive thickness. Through a comprehensive analysis of these factors, along with the properties of adhesives and composites, the study aims to enhance the understanding of their impact on repair efficiency. The findings are intended to provide valuable insights for designers of bonded composite repairs, facilitating better predictions of the fatigue life of repaired structures. This study investigates the effectiveness of crack repairs by analyzing the stress intensity factor at the crack front as a key fracture criterion. A comprehensive examination of various repair parameters is conducted to assess their impact on repair efficiency. Utilizing Finite element method numerical simulations in ABAQUS, the research evaluates the performance of bonded composite joints under different conditions. The findings from these simulations are compared to experimental data, providing valuable insights into the fatigue life of repaired structures. This work aims to enhance the understanding of repair methodologies and their implications for structural integrity in engineering applications.

Keywords: Composite patch, Crack, Stress intensity factor, Finite element method

Introduction

To increase the usable life of older aircraft, broken parts need to be replaced or repaired. Using crack arrestment techniques is frequently the most cost-effective way to restore the component's capacity to withstand loads if there are few cracks and the size of the cracks is minor in comparison to the component's size. The great rigidity, high strength, and low weight of the composite have demonstrated the process's immense promise for reinforcing the fractured structure. The stress analysis of the recovered structure and the ensuing development of stress intensity variables are among the trickiest parts of bonded composite repair technology.

The issue is that if composite patches were symmetrically (double sided) or unsymmetrically (single sided) glued to the sides of a plane stress metallic panel, under in-plane pressure, the panel would acquire incredibly complex three-dimensional stresses. Stress analysis may make use of three-dimensional finite elements. However, in addition to the clearly high computational cost, using components with high aspect ratios may cause convergence issues because of the thinness of the adhesive layer and patches. As such, the majority of research to date has been on creating instruments for more straightforward analysis.

The necessity for the structure or component to be sturdy and solid is one of the primary constraints placed on the builder. The capacity of a part or structure to withstand the effect of several factors that may cause it to become unbalanced is known as stability (Rezaifar,2014). A structure or component may fail or receive damage after being produced, even with the best quality control. One of the most common kinds of damage that components may get is a crack. The component gets weaker and is subjected to higher stresses when fractures appear, which might result in plastic deformation or collapse (Caballero,2008). In adhesively bonded joints subjected to mechanical or thermal loading, stress is distributed throughout the adhesive layer from the softest to the stiffest adherend. This feature aids in the restoration of damaged aircraft structures using bonded composite patches. Patch bonding increases the residual fatigue life by lowering the stress at the fracture site (Bhadra, 2021).

Stress is transferred from the softest to the stiffest adherend in the adhesive layer of joints that are subjected to mechanical or thermal loading. This feature facilitates the use of bonded composite patches to restore damaged airplane structures. By reducing the tension at the fracture location, patchbonding lengthens the residual fatigue life, as shown by Katlan et al. (2013), Okafor et al. (2005) and (Baker et al. 2003). The main advantage of the bonded composite repair (BCR) procedure is the uniformity of stress transfer across the bonded zone, which extends the fatigue life of the reconstructed structure. Stress concentrations are avoided, in contrast to fixed doublers where stress zone concentrations are inevitable. A method known as "Crack Patching" was developed in the early 1970s by the Aeronautical and Maritime Research Laboratories (AMRL) for the Royal Australian Air Force (RAAF) to use high-strength advanced composite materials to fix metallic aircraft components that had cracks (Baker, 1991).

Using an adhesive bonding approach, the composite reinforcement, also known as a patch, may be mechanically bonded or adhered to the compromised or damaged structure. Adhesively bonded composite patches have several advantages over mechanically fastened repair methods, including the elimination of needless fastener holes in already-weakened structures, reduced installation costs, enhanced fatigue life and strength for effective crack retardation, shortened repair times, decreased stress concentrations at fasteners, corrosion resistance, high stiffness, and lightweight design.

The unpredictable nature of the repair's integrity is one problem prohibiting the regular usage of composite patches to replace damaged metallic aircraft components. Estimating the strength and lifespan of the restored structure as well as the distribution of stress inside it are additional factors that must be taken into account when planning a bonded composite patch repair for metallic constructions with cracks. Sun (1996) provided a simple analytical method for analyzing aluminum plates that have been repaired using composite patches applying Midlin plate theory. To simulate the adhesive layer, strong springs were employed to join the aluminum plate and patch. A three-dimensional finite element analysis was performed using the commercial program ABAQUS, and the stress intensity factors resulting from the two cases were compared.

Structural parts have an inherent weakness that eventually shows up as a fracture. Adhesively bonded composite patch-based repairs have a better structural efficiency than traditional repairs. By replacing the stressed state before a crack tip, the composite patch repair lowers the stress intensity factor (SIF) to a level that can be controlled. Bonded composite patches provide excellent weight transfer characteristics and an alternative load path, making them useful for repairing broken structures (Mangalgiri, 1999). In airplane applications, advanced composite materials—typically composed of continuous carbon fibers embedded in a polymer matrix—can offer better material qualities than metals, allowing for the fabrication of lighter structural components (Soutis, 2005). Since fewer fuels are used to power the lighter structures, emissions are decreased. In the 1960s, composite materials were initially used in military aircraft; in the 1970s, they were also used in civilian aircraft (Edwards, 2008). But civil aircraft manufacturers didn't start using composites in significant structural applications until the 2000s. (Denney & Mall,1997) Modern composites are presently being used in place of conventional materials by top aircraft manufacturers, allowing composites to reach their full potential in creative structural designs. Nowadays, main and secondary structural applications in aircraft design employ carbon-reinforced polymer composites.

Patch debonding is almost often the main cause of unsuccessful repairs. Research studies have not given much emphasis to the examination of this physical phenomenon in the context of patch healing. Thus, Denney and Mall (1997) have used fatigue testing to examine how debonding affects the durability and strength of the repair. This author demonstrates that when the amount of debonding rises, the restored structure's service life decreases. According to Deheeger (2009) the shear stresses induced in the adhesive joint are responsible for the debonding. The mechanical and geometric properties of the adhesive junction play a major role in determining how effectively the repair functions (Albedah, 2017; Davis, 1995). The adhesive is the least robust part of the plate/adhesive/- composite patch systems because of its low rigidity. In actuality, the adhesive's deterioration accounts for 53% of the failures seen in aircraft structures repaired with composite patches. (Megueni, 2004).

In another study (Bouiadjra, 2008) it was demonstrated by examining various debonding configurations that debonding rises across a wide central width and causes the repair patch's edge to become disbonded. Zarrinzadeh et al (20) investigated the process of adhesive film debonding from a fractured portion of pipeline to the composite repair. They show how cohesive zone model (CZM) and XFEM modeling tools may be used to foresee a more realistic behavior of the structure.

Sahli (2017) studied both analytically and practically using sonic emission to analyze the debonding process during airplane patch repair. They show that adhesive damage starts at the free edges of the structure and in the area around the notch. Magalhães (2005) demonstrated that, as opposed to the adhesive layer failing owing to crack growth, an area wounded by microcracking or microcavitation starts and spreads. According to these writers, harm propagates inside the adhesive close to the adhesive contact. The presence of a little sticky coating on the connected surface indicated that the fracture was cohesive even though it seemed to be adhesive. Literature has focused primarily on the adhesive disbanding that happens during the repair process. Recently, several studies describing the impact of adhesive failure on repair effectiveness have been published. (Qing, 2006)

Bachir Bouiadjra et al. (2008) examined how adhesive disbanding affected the bonded composite repair procedures used in aircraft structures. According to their research, the presence of the adhesive disbands increases the stress intensity at the tip of repaired cracks which can reduce the repair efficiency. Ouinas (2012) examined the behavior of an adhesively bonded composite patch used to repair a progressive edge fracture in an aluminum plate under full width stress. This investigation showed that, the reduction of the stress intensity factor at the crack tip increases with the patch thickness for disband width higher than crack size (Bouiadjra, 2012). It is known that a reduction of the adhesive thickness decreases the stress intensity factor, it means that lower adhesive thickness is desirable for repairing cracks (Bachir Bouiadjra, 2002) the lower thickness well supports the transfer loads towards the patch but increases the risk of the adhesive failure. To foresee this risk, it is necessary to consider a disbond.

In this work, the behavior of a cracked aluminum plate repaired with composite patch was studied, in order to investigate the variation of stress intensity factor along the variation of the crack size, and the type of patch used. The cohesive characteristics and resistance to disbond, as determined by stress intensity factor, characterize the interfacial cohesive zone of the patch, adhesive, or plate system was also investigated. The findings demonstrate that damage to the adhesive, plate assemblies, and patch may be accurately predicted by simulations that are based on the CZM model.

Geometrical model

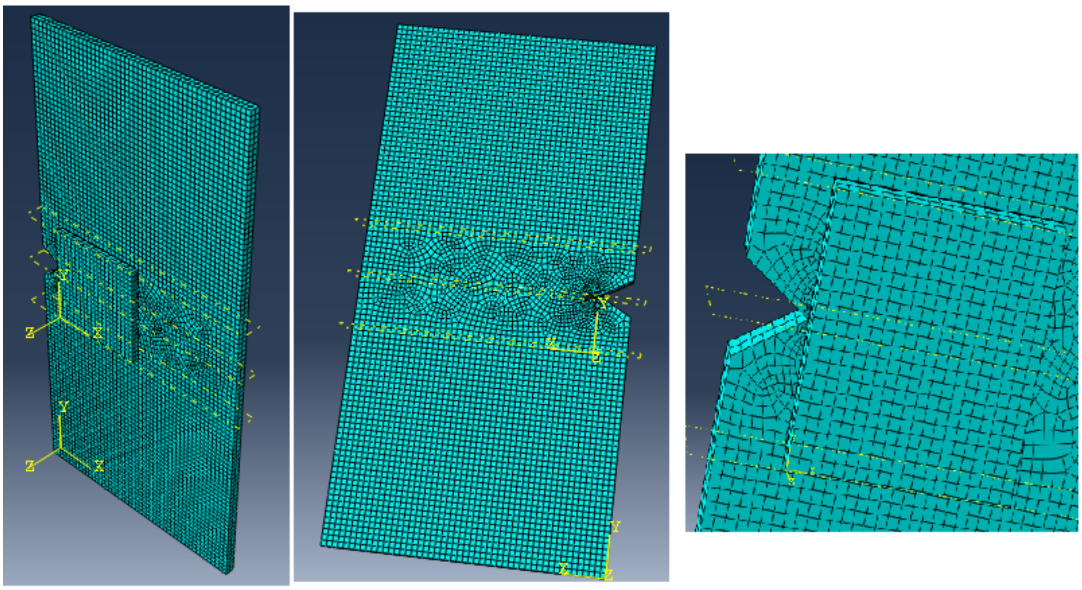

Figure 1. Typical mesh model

The model is an Aluminium plate, with a length L=100mm, with=50 mm, , crack size 6mm, crack opening α=60 degree, load= tensile load

Aluminum E=71700MPa μ=0.33

We used a calculation code "Abaqus" version 6.14 for the analysis of composite structures by the finite element method. This code presents a complete system, integrating not only the calculation functions themselves, but also functions of model construction and processing of results Mesh of the plate and the Composite Patch 11526 linear hexahedral elements of type C3D8R: An 8-node linear brick, reduced integration, hourglass control. ABAQUS (2019). Mesh along the adhesive 400 linear hexahedral elements of type COH3D8: An 8-node three-dimensional cohesive element (Figure 1). The Figures below show stress intensity factor variation depending on the crack size, for the unrepaired aluminum plate for different tensile loads, and repaired with boron epoxy patch, and adhesive FM73

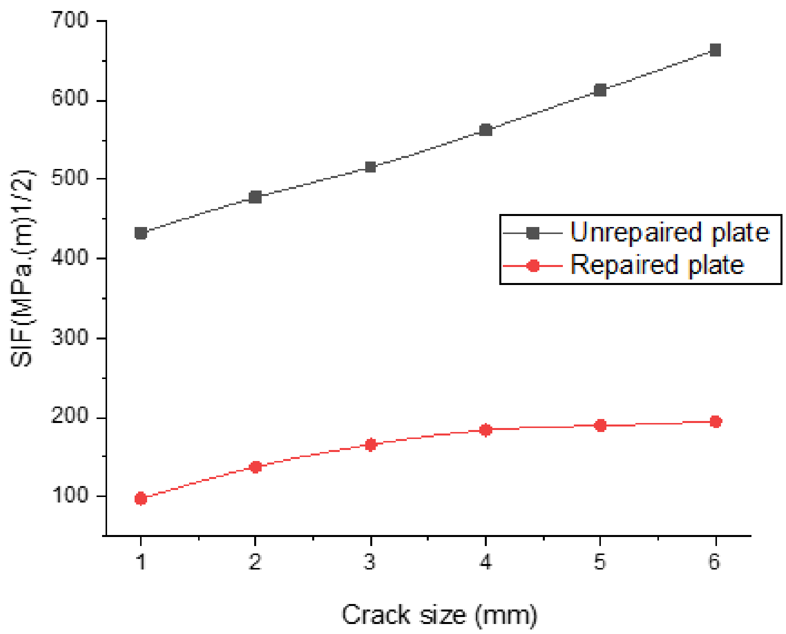

Figure 2. SIF variation depending on the crack size for 70MPa

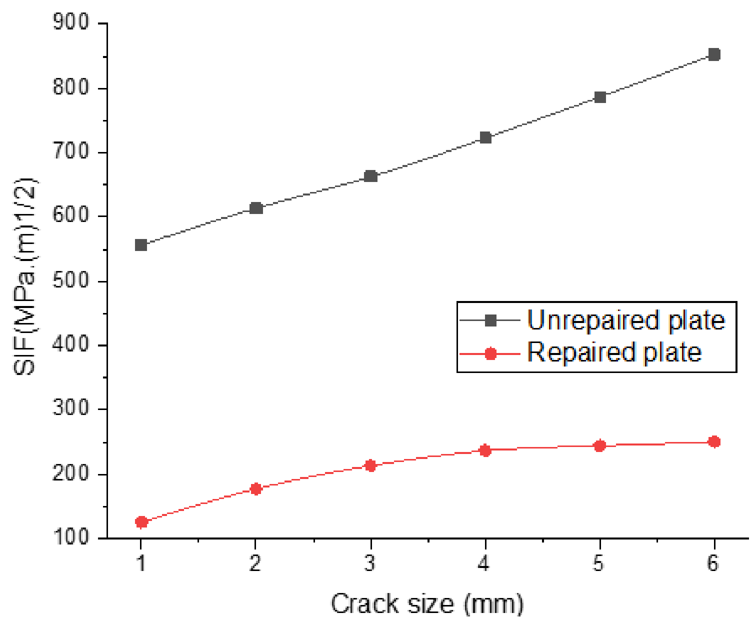

Figure 3. SIF variation depending on the crack size for 90MPa

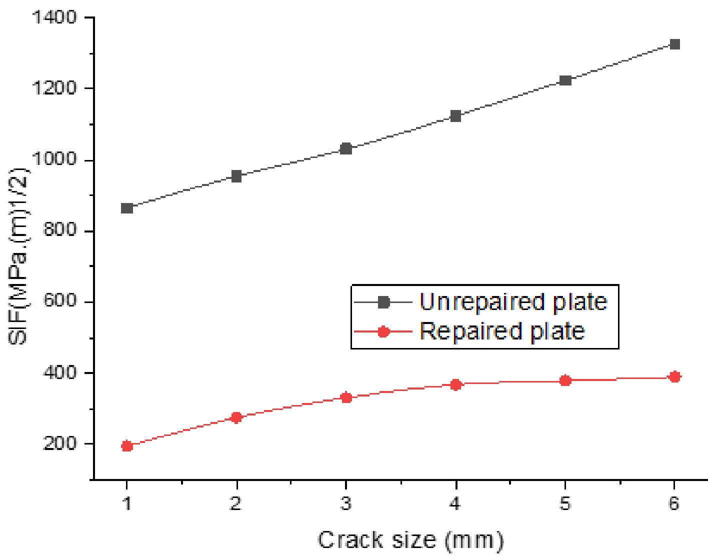

Figure 4. SIF variation depending on the crack size for 140 MPa

The Figure shows Von Mises stress variation depending on the crack size for optimized adhesive and patch (adhesive AV138, Patch boron-epoxy,lengths, and width =20mm)

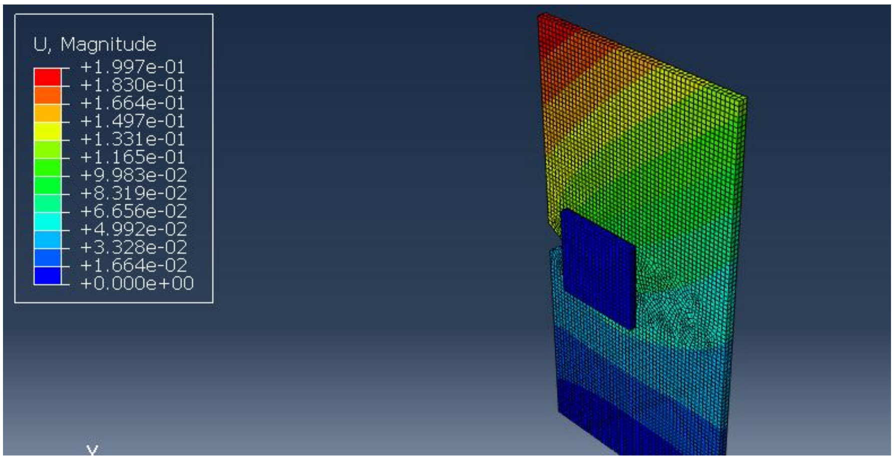

Figure 5. Von Mises stress variation depending on the crack size for

Conclusion

By examining the stress intensity factor at the crack front as a crucial fracture criteria, this study examines the efficacy of crack repairs. To determine their effect on repair efficiency, a thorough analysis of several repair parameters is carried out. The study assesses the performance of bonded composite joints under various circumstances using numerical simulations in ABAQUS using the Finite element approach. By comparing the results of these models with experimental data, important information about the fatigue life of restored structures is revealed. The purpose of this effort is to improve knowledge of repair techniques and how they affect structural integrity in engineering applications.

Recommendations

Incorporate sensor networks within the repair patch to allow for real time strain monitoring and early fracture reactivation or debonding identification. To forecast the safety and remaining service life of the repaired column, develop a reliability-based model that takes loading and fracture size uncertainty into consideration.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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